ECE 595

M02A-CELLULAR NETWORK EVOLUTION

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1st Generation (1G)

- Designed to carry only analog voice.
  - The data is analog (voice), similar to the public telephone network.
- Use FDMA (Frequency Division Multiple Access) technology for allocating channels to users. Each user is given one channel.
- The most popular 1G system is AMPS (Advanced Mobile Phone Service)
  - Used in the early 1980s
  - High energy consumption (last ~30 mins conversation)
  - High interference
  - Low traffic capacity

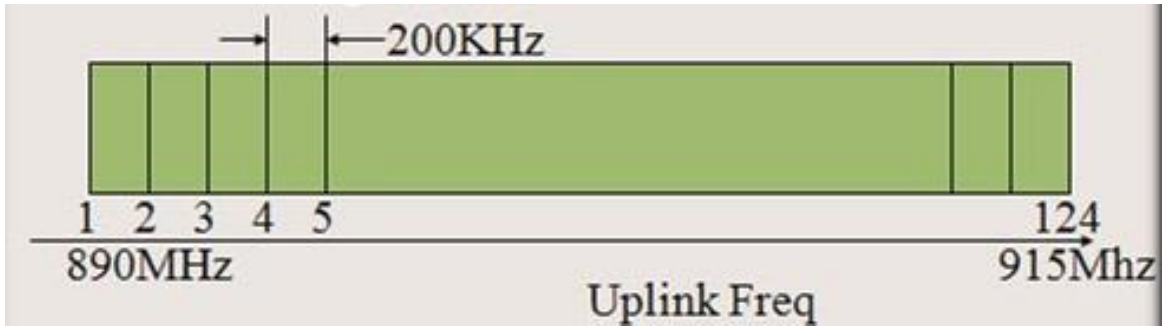
2nd Generation (2G)

- The second-generation systems are developed to provide:
  - Higher quality signals.
  - Higher data rates to support digital services.
  - Higher capacity.

- The main difference between 1G and 2G is that 2G systems send digital signals.
  - Voice is digitized before it is sent.
  - But transmission is done using analog signal (all wireless signal is analog).
  - Allows for services such as SMS.

2G technologies

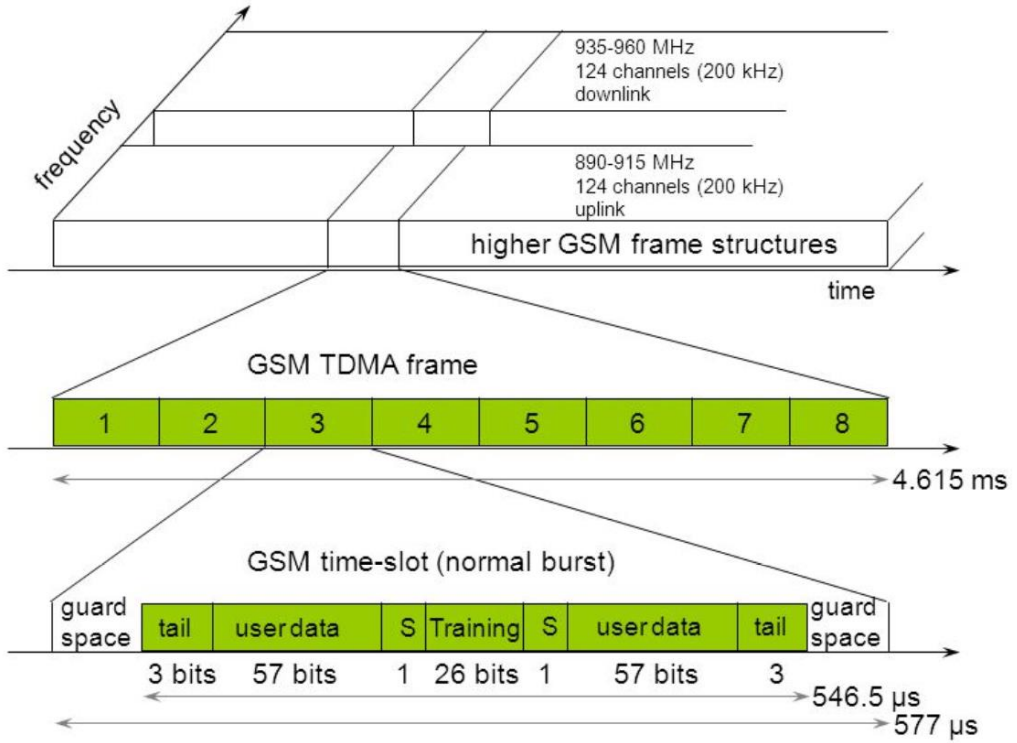
- GSM (Global System for Mobile Communications).
  - ✓ Started off in Europe in the early 1990s.
  - ✓ Also used in Asia and North America.
  - ✓ It uses FDMA and TDMA
    - Uplink uses 890-915 MHz frequency band (25 MHz)
    - Downlink uses 935-960 MHz frequency band (25 MHz)
    - Number of channels in the uplink/downlink = 124
    - Amount of bandwidth of each channels = 200 kHz



2nd Generation (2G)

2G technologies

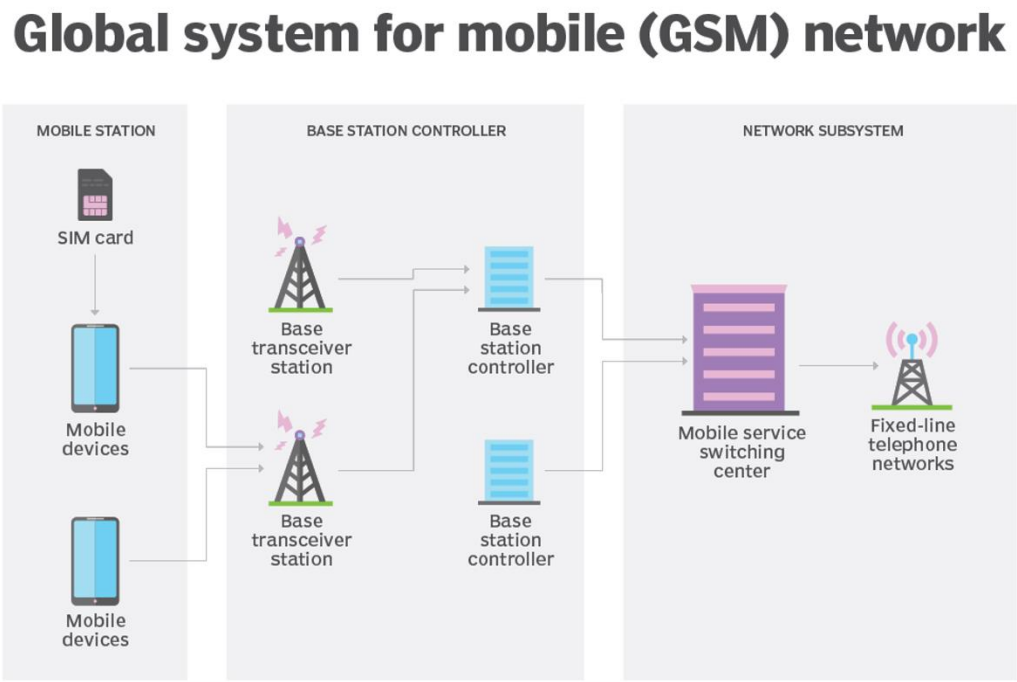
- GSM (Global System for Mobile Communications).
  - ✓ It uses FDMA and TDMA
    - TDMA frame—4.615 millisecond (ms)
    - 8 time slots (normal burst) in a TDMA frame
    - Each time slot has 576.875 μs
    - Modulation: GMSK (~3.692 μs/bit)
    - Channel rate=270.8 kbps
  - ✓ Each user is allocated one time slot in a specific TDMA frame to transmit/receive its data/voice
    - Channel capacity per user=33.85 kbps
    - User data rate per channel=24.7 kbps (actual user data rate=9.6 kbps)
  - ✓ GSM is still a circuit switch network
    - Highly inefficient for burst traffic



2nd Generation (2G)

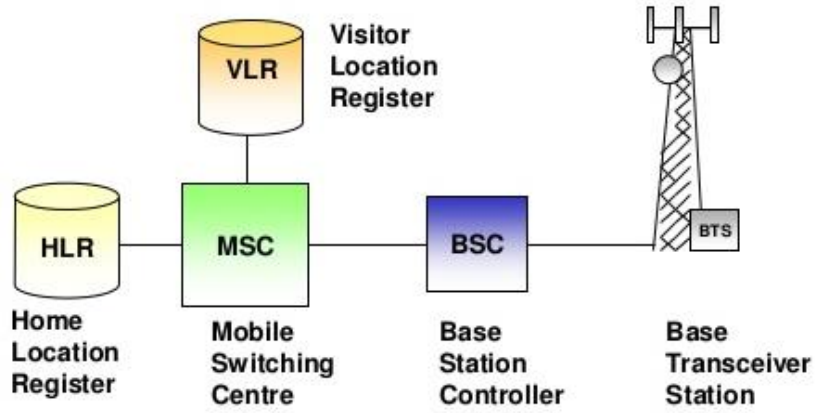
2G technologies

- GSM Network
  - ✓ BTS
    - Contains radio transceivers
    - Communicates with MS and BSC
  - ✓ BSC
    - Controls a group of BTSs
    - Manages the radio resources, controls handoffs within the group of BTSs
    - Communicates with MSC and BTS
  - ✓ MSC
    - Controls handoffs
    - Acts as a switching node
    - Provides an interface to the PSTN
  - ✓ Home Location Register, Visitor Location Register, Equipment Identity Register, Authentication Centre, Gateway Mobile Switching Centre, SMS Gateway.



2G technologies

- HLR: a central database of all permanent subscriber information in the GSM system.
  - ✓ Identifications of an MS, e.g., IMSI
  - ✓ Subscription information: related services option (Teleservices, Bearer Services, and Supplementary Services (e.g., missed call alert, caller tone, etc.)).
  - ✓ Service limitations (e.g., roaming limitation).
  - ✓ Identity of an MS's associated VLR—indicating the location of the MS.
  - ✓ Authentication Key.
  - ...



- VLR: a temporary database for the MSs
  - ✓ Normally, each MSC is associated with a VLR.
  - ✓ The VLR contains a copy of most of the data stored at the HLR. It also contains some additional data
    - Location area (LA) of each local MS
    - Mobile status (busy/free/no answer etc.).
    - Temporary Mobile Subscriber Identity (TMSI).
    - Mobile Station Roaming Number (MSRN).
  - ✓ The database entry of the MS is deleted when the MS leaves the service area.

2G technologies

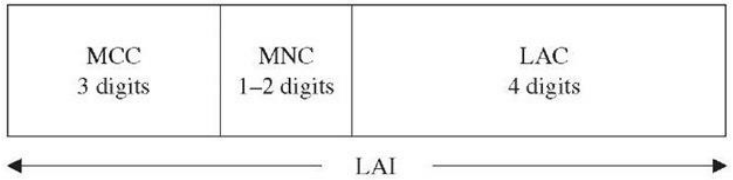
Location Management

- ✓ In the GSM network, the MS may be anywhere within the network.
- ✓ A mechanism is needed to locate the destination MS in order to deliver data to it.
- ✓ Location management refers to the activities performed by the wireless network to keep track of the MS.
- ✓ In the GSM network, the location management must identify the destination MS is currently located under which BTS's coverage area.
- ✓ Location management consists of two major parts
  - Location update
  - Paging

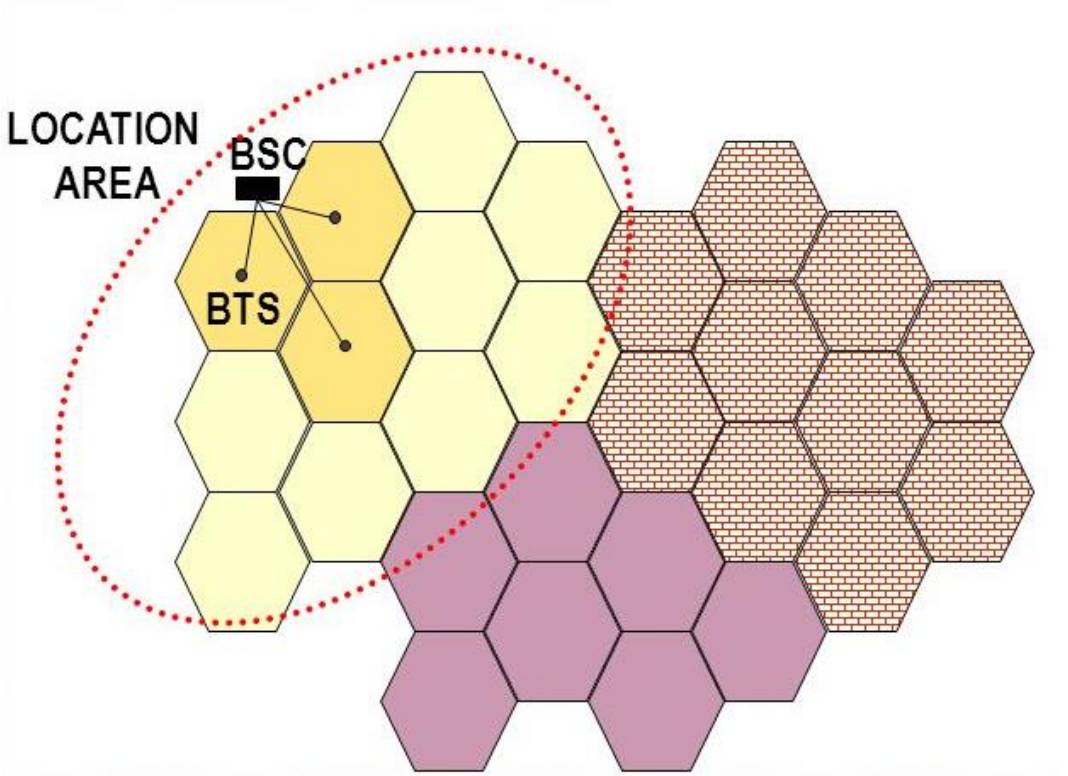
2G technologies

Location Management—Location Area

- Location area (LA): an area covered by a number of cells/BTSs.
- Each LA is identified by a Location Area Identification (LAI)



  - MCC=Mobile Country Code
  - MNC=Mobile Network Code
  - LAC=Location Area Code
- One VLR may control many LAs
- Each BTS periodically broadcasts its LAI via control channel (BCCH)



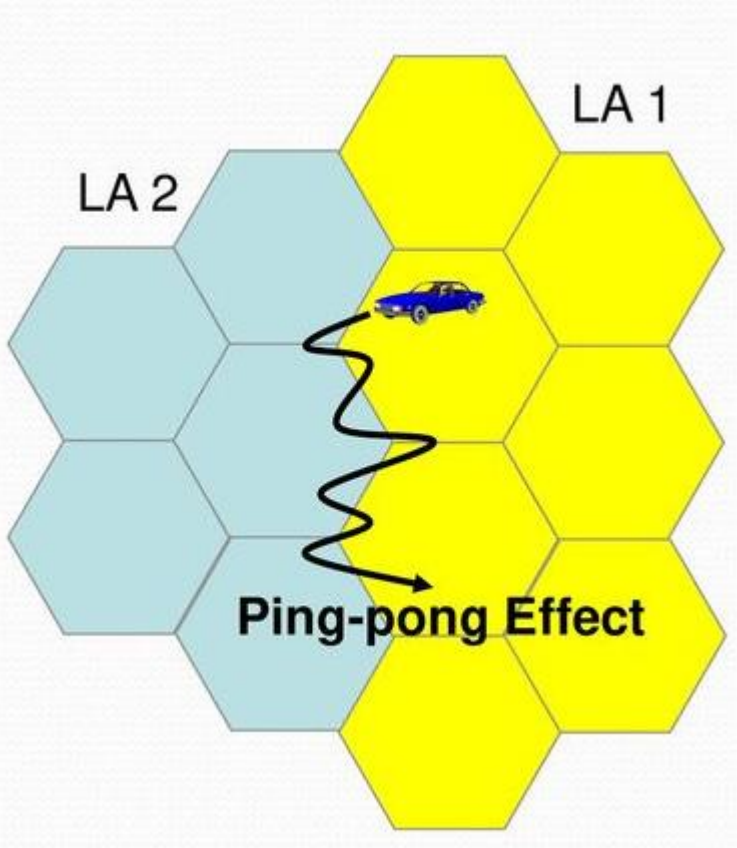
2G technologies

Location Management—Location Update

- ✓ Once an MS receives a LAI different from the one it stores, the MS would trigger the location update process.
- ✓ Two types of location updates
  - Intra-VLR location update: An MS cross the border of two LAs associated to the same VLR.
    1. The MS sends a location update request to the VLR
    2. The VLR update the LAI of the MS
  - Inter-VLR location update: An MS cross the border of two LAs associated to the different VLRs.
    1. The MS sends a location update request to the new VLR
    2. The new VLR copy the user profile of the MS from the old VLR and update the LAI
    3. The new VLR updates the MS associated VLR ID in the HLR
    4. The old VLR delete the user profile of the MS
- ✓ One VLR may control many LAs

2G technologies

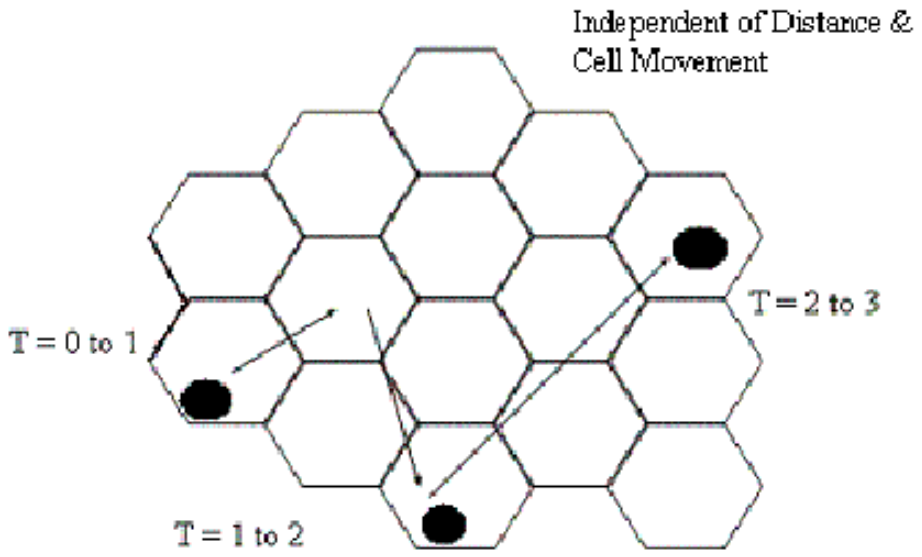
- Location Management—Location Update
  - ✓ Ping pong effect: an MS moves repeatedly between the boundaries of two or more location areas.
  - ✓ Ping pong effect may significantly increase the location update cost.
  - ✓ How to avoid Ping pong effect?



2G technologies

Location Management—Dynamic Location Update

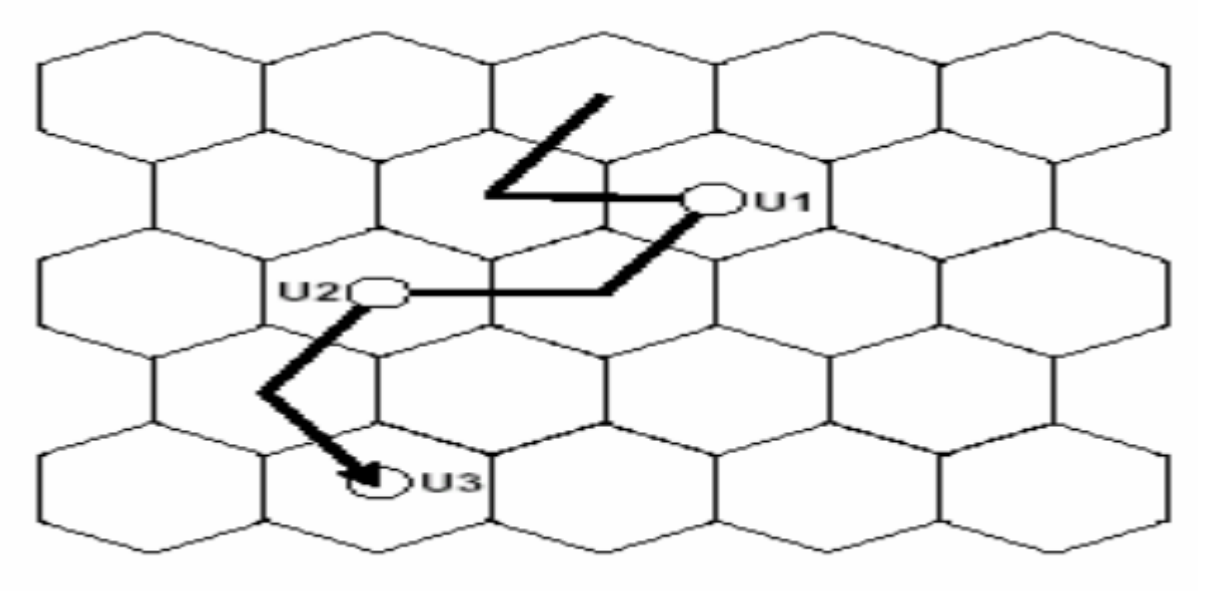
- ✓ Periodical location update: an MS update its location at each time interval.



2G technologies

Location Management—Dynamic Location Update

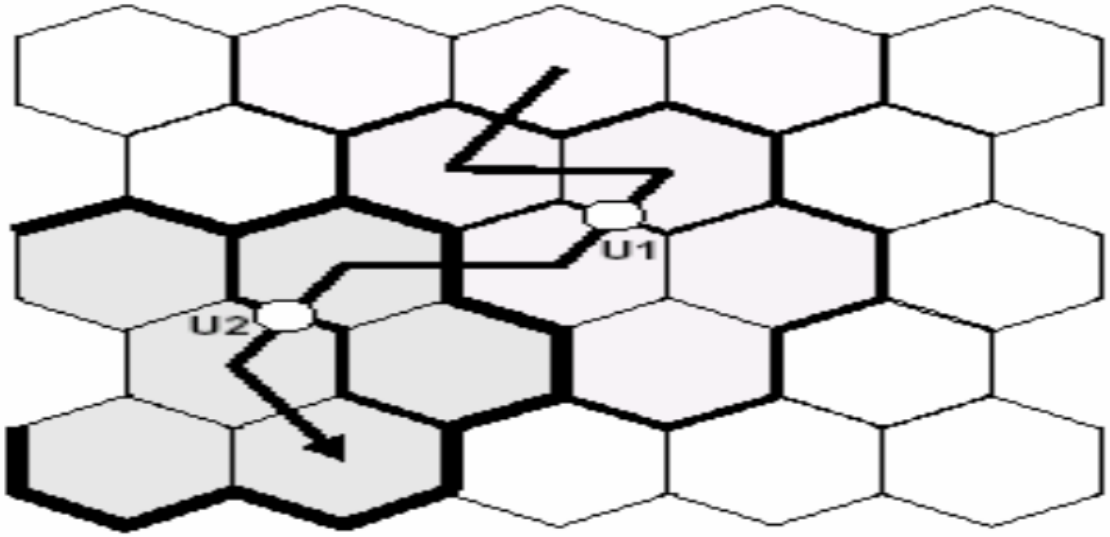
- ✓ Movement-based location update: an MS updates its location after a given number of boundary-crossings to other cells in the network.



Number of boundary crossing=2

2G technologies

- Location Management—Dynamic Location Update
  - ✓ Distance-based location update: an MS performs a location update when it has moved a certain distance from the cell where it last updated its location.



  - ✓ Profile-based location update: both the VLR/HLR and the MS maintains a list of the LAs/cells, where the MS frequently visits. The MS would update its location only when entering a LA/cell not contained in the list.

2G technologies

Location Management—Paging

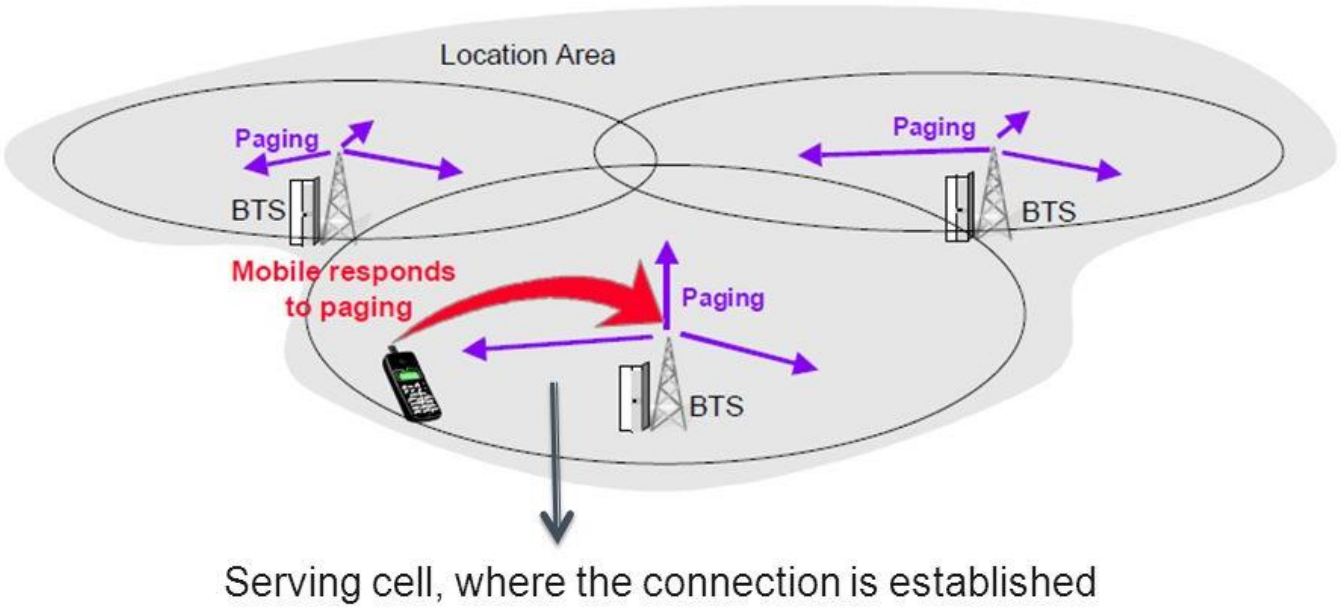
- ✓ When there is an incoming call/SMS, the network should be able to precisely determine the current cell location of an MS to be able to route an incoming call.
- ✓ Paging is a procedure that the network uses to find out a specific MS's location (i.e., the MS in which cell's coverage) before actual call established.
- ✓ Paging is used to alert the mobile station of an incoming call.
- ✓ However, from the network point of view, the granularity of the MS's location is normally in the LA level, and so how the network knows the exact location of the MS?

2G technologies

Location Management—Paging

✓ Simultaneous paging

- The paging query would send to all the cells in the LA.
- Each cell broadcasts the paging query via the paging channel (PCH) to its MSs.
- Once the MS receive the query, it will respond to it accordingly.
- Simultaneous paging incurs a low paging delay, but a high paging cost.



2G technologies

Location Management—Paging

- ✓ Sequential paging
  - Paging one or a number of cells sequentially, rather than paging all the cells in the LA.
  - The order by which cells being paged is critical to the performance.
    - Purely random order
    - Paging of cells in the order of decreasing user dwelling possibility.
- ✓ Intelligent paging
  - An optimized version of sequential paging
  - Predict the location of the MS.

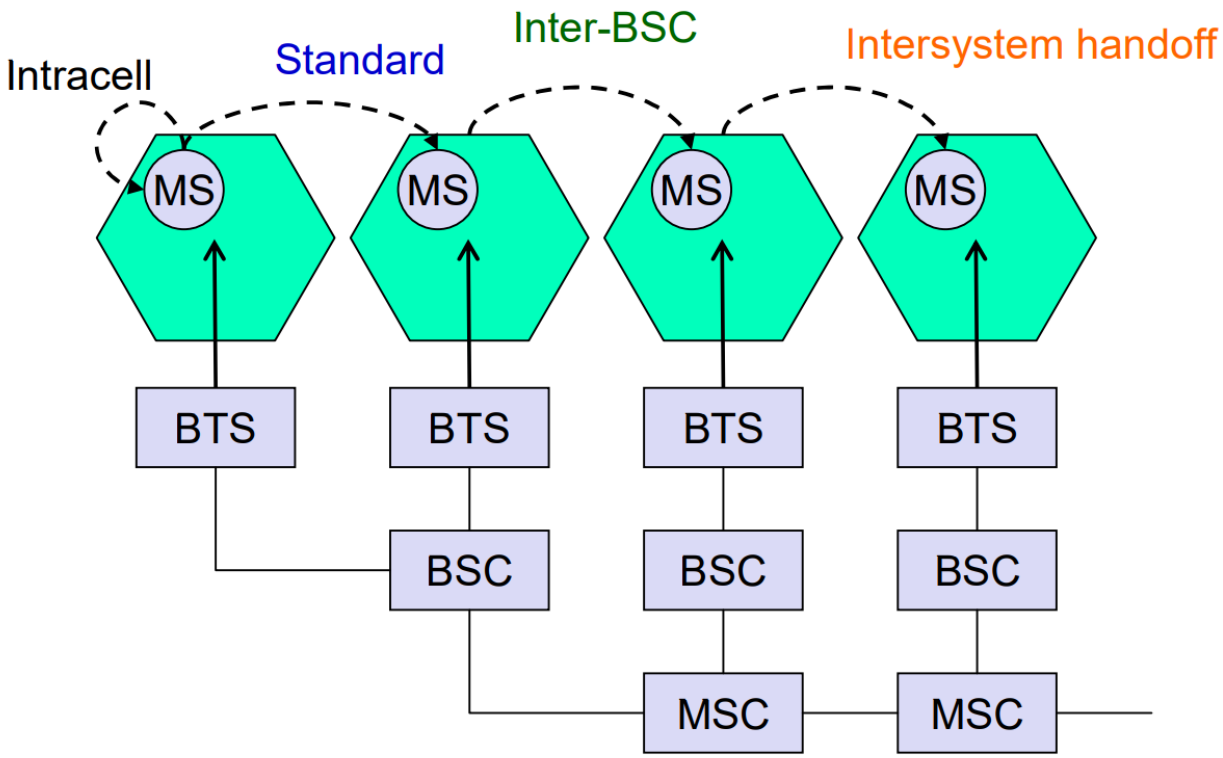
2G technologies

- Location Management—Tradeoff between location update and paging
  - ✓ Reducing the size of LA may reduce the cost of the paging.
    - May reduce the number of paging query
    - If one LA=one cell, then?
  - ✓ Reducing the size of LA may increase the cost of the location update
    - MSs may have to update their locations more frequently → increase of the energy consumption of MSs
    - If one LA=entire network, then?
  - ✓ Location management is to optimize the tradeoff between location update and paging

2G technologies--Handoff

- Handoff in GSM
  - ✓ Handoff (Handover) refers to the process of transferring an ongoing call or data session from one channel connected to the core network to another channel.

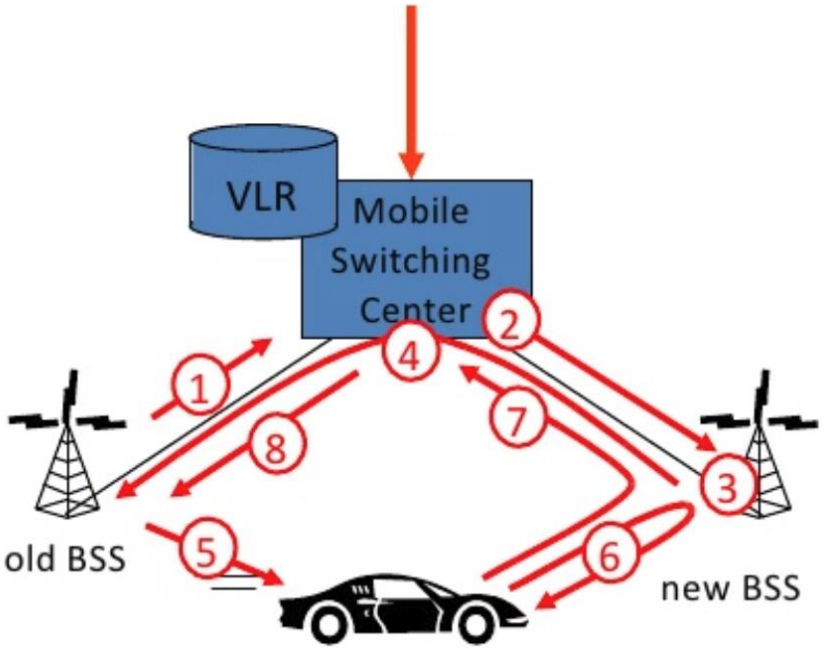
- Types of Handoff in GSM
  - ✓ Intra-BTS
    - Handoff between sectors of same BTS.
  - ✓ Inter-BTS (Standard) handoff
    - Handoff between two BTSs, both of which are connected to the same BSC.
  - ✓ Inter-BSC handoff
    - Handoff between two BTSs, which are connected to the different BSCs, but within the same MSC.
  - ✓ Inter-MSC (Intersystem) handoff
    - Handoff between two BTSs within the different MSCs.



2G technologies--Handoff

Procedures of Handoff in GSM (Inter-BSC handoff)

1. A BTS or MS notices signal is weakening (when the received signal strength goes below a certain threshold value). The BTS sends a handoff measurement request message to its MSC.
2. The MSC determines the new BTS and sets up the path (allocates resources) to the new BTS.
   - ✓ neighbor base stations to report their reception of mobile's signal strength on uplink
   - ✓ MS to measure strength of neighbor base stations on downlink—Mobile Assisted Handoff
3. The new BTS is allocated a radio channel for use by the MS.
4. The new BTS signals MTS and the old BTS: ready.
5. Old BTS tells the MS: perform handoff to the new BTS.
6. The MS signals to the new BTS to activate the channel.
7. The MS signals to the MSC (via the new BTS) to inform that the handoff is completed. The MSC will then reroute the call to the MS via the new BTS.
8. The path between the MSC and the old BTS will be released.



Transition from 2G to 3G (2.5 G)

2.5G technologies

- The 2G systems are optimized for voice service and not well adapted for data communications.
- 2.5G systems enhance the data services over 2G
  - ✓ Send/receive emails
  - ✓ Web browsing
- Technologies
  - ✓ High-speed circuit-switched data (HSCSD)
  - ✓ General Packet Radio Service (GPRS)
  - ✓ Enhanced Data Rate for GSM Evolution (EDGE)
  - ✓ 1xEV-DO
  - ✓ 1xEV-DV

Transition from 2G to 3G (2.5 G)

2.5G technologies

High-speed circuit-switched data (HSCSD)

- ✓ First attempt to get high-speed data over GSM
- ✓ Allow users to get up to 8 time slots
  - Data rate up to 115 kbps
- ✓ Circuit switch
  - Constant data rate
  - Not suitable for burst traffic

General Packet Radio Service (GPRS)

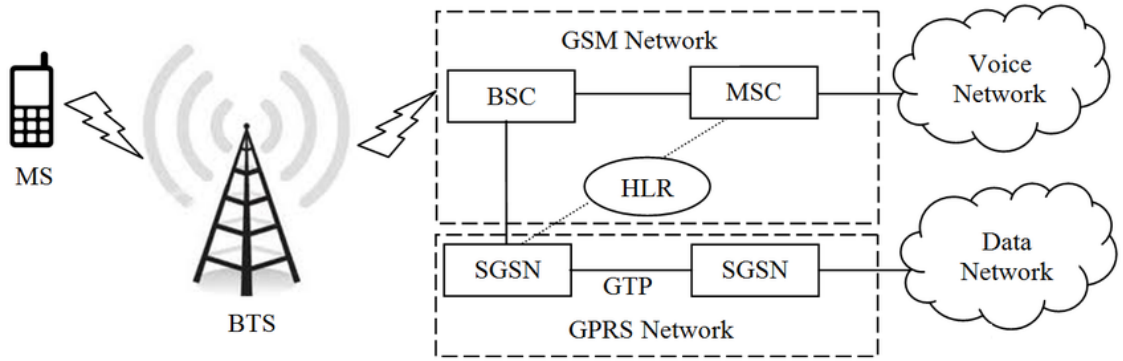
- ✓ Allow users to get up to 8 time slots
  - Date rate up to 171 kbps
- ✓ Packet switch—add two new elements in the cellular networks
  - Service GPRS support node (SGSN)
  - Gateway GPRS support node (GGSN)

Transition from 2G to 3G (2.5 G)

❑ 2.5G technologies

➢ General Packet Radio Service (GPRS)

- ✓ BTS has to be upgraded to support packet switching
  - To support packet transmission between BTS and MS
  - To allow packet transmission between BTSs
- ✓ BSC has to be upgraded to support packet switching
  - Installation of new hardware called the packet control unit (PCU) to direct data traffic to the GPRS network
- ✓ Service GPRS Support Node (SGSN)
  - Protocol conversion and routing
  - mobility and session management…
- ✓ Gateway GPRS Support Node (GGSN) –gateway to the external world.



Transition from 2G to 3G (2.5 G)

2.5G technologies

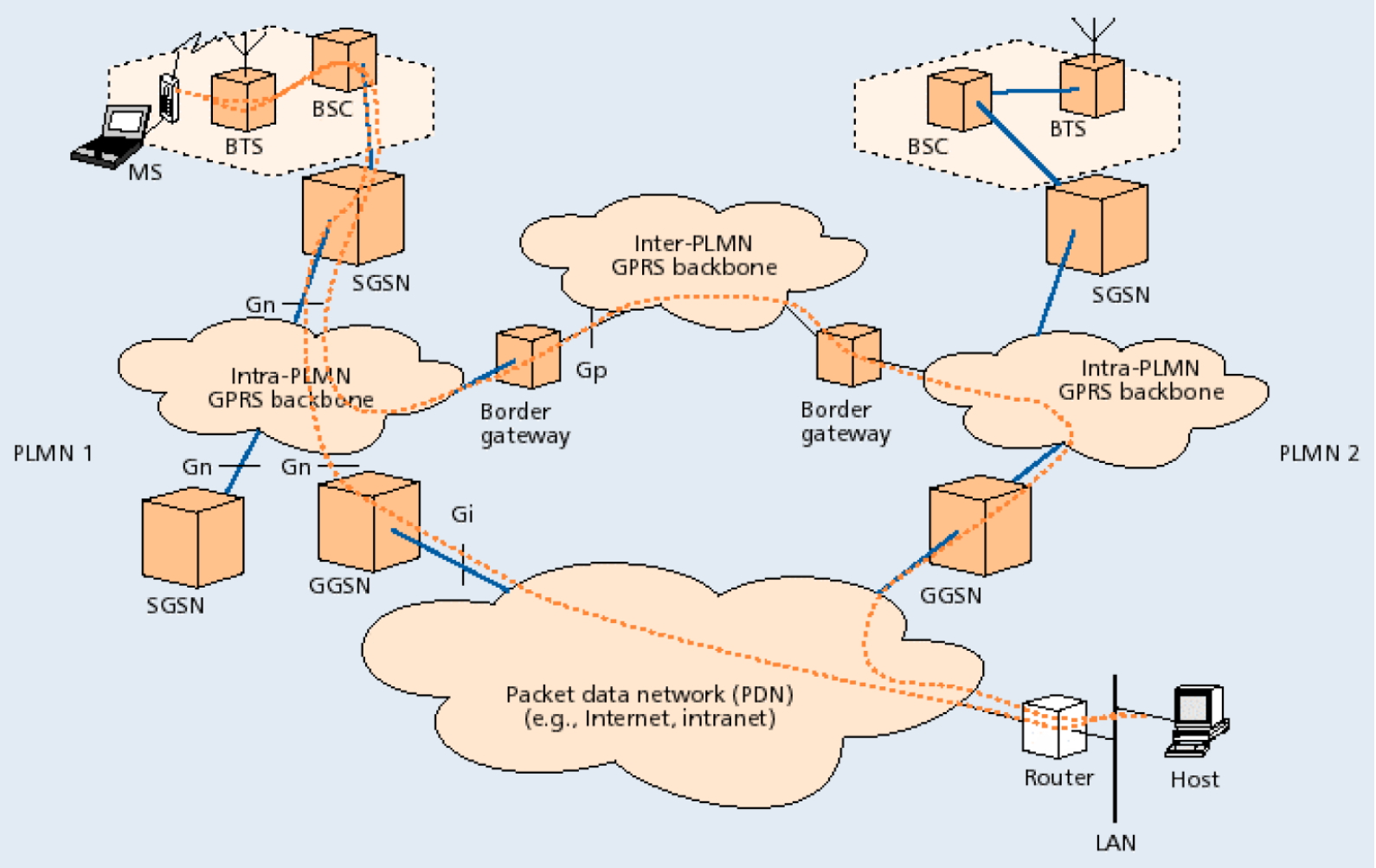
- General Packet Radio Service (GPRS): packet switching VS circuit switching

	Circuit Switching	Packet Switching
Channel Allocation	for entire call period one user uses complete traffic channel	only if needed (capacity on demand) several users share one traffic channel (statistical multiplexing)
↓	↓	↓
User pays for ...	duration of call	amount of transmitted data
↓	↓	↓
For bursty traffic	Inefficient	Efficient

Transition from 2G to 3G (2.5 G)

2.5G technologies

- GPRS: System view



Transition from 2G to 3G (2.5 G)

2.5G technologies

GPRS: Session management—GPRS attach and detach

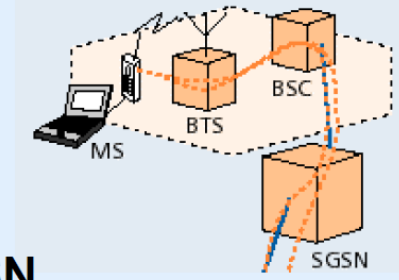
To use GPRS services

⬇

MS must **attach** to network

⬇

MS / user registers with an SGSN



SGSN:

- Checks if user and MS are authorized to use network?
- Copies user profile from HLR.
- Assigns a P-TMSI (Packet-TMSI) to user.

Transition from 2G to 3G (2.5 G)

2.5G technologies

GPRS: Session management—PDP Address and PDP Context

To exchange packets with PDN after attach

⬇

MS applies for address used in the PDN

⬇

Packet Data Protocol Address (PDP Address) e.g. IP address

PDP Context: describes characteristics of session

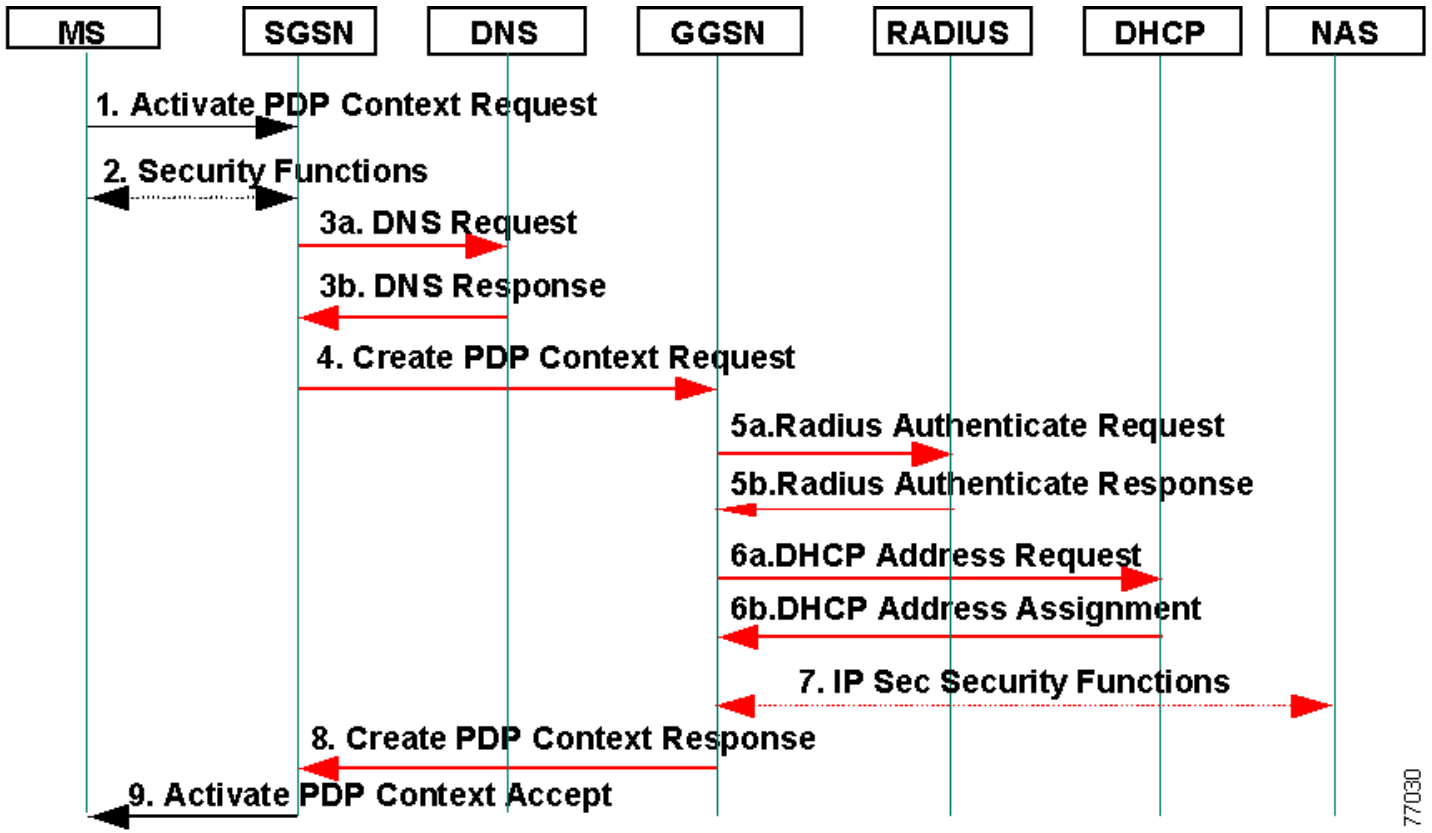
- PDP Type (e.g., IPv4)
- PDP Address (e.g., 129.187.222.10)
- requested QoS
- address of GGSN which is access point to PDN

Active PDP context: MS is "visible" for the external PDN (can send and receive packets)

Transition from 2G to 3G (2.5 G)

2.5G technologies

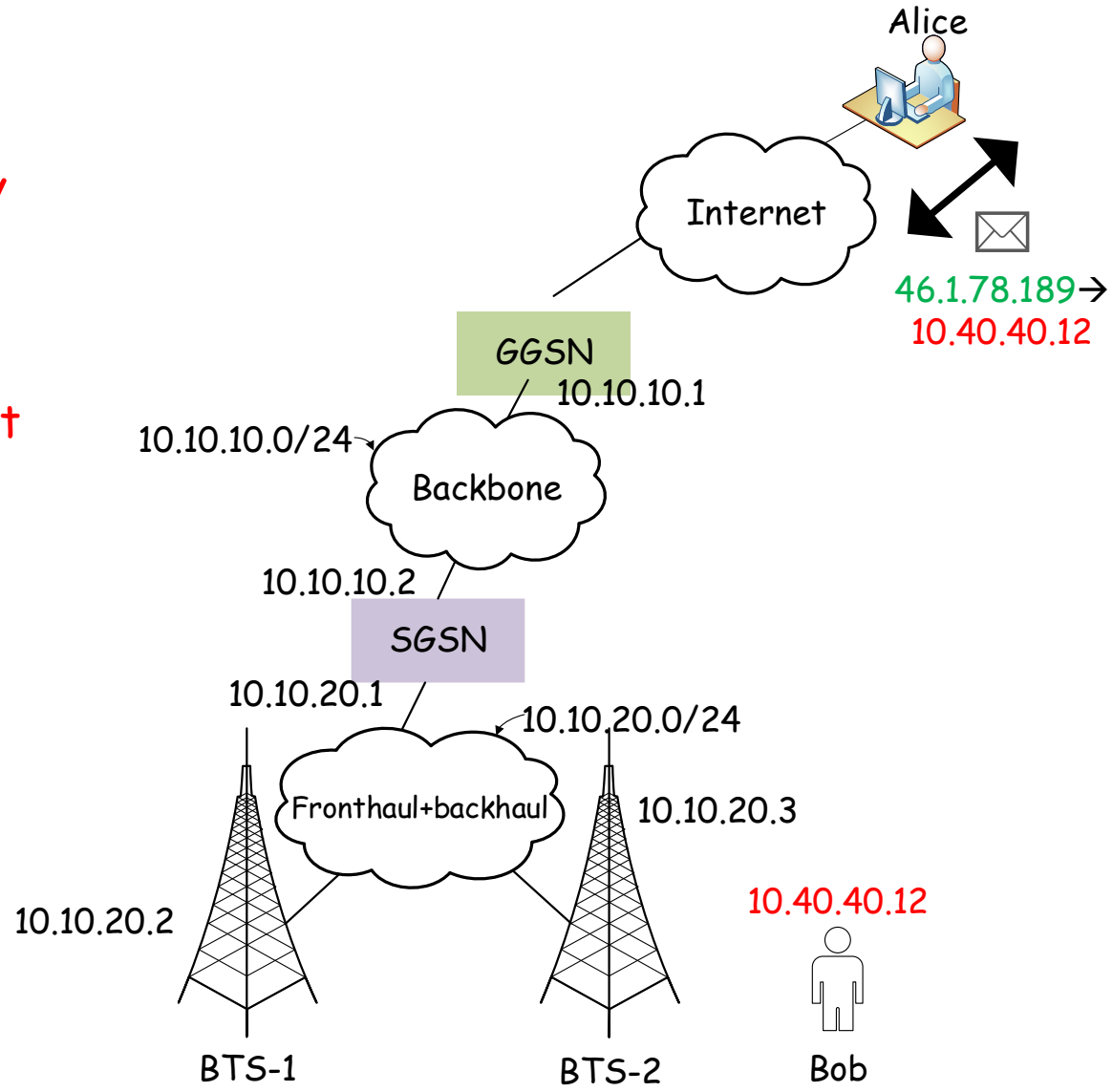
GPRS: Session management—PDP Context Activation



Transition from 2G to 3G (2.5 G)

2.5G technologies

- GPRS: Session management—topologically incorrect
  - ✓ Topological incorrect: an MS and its connected BTS are not in the same subnet owing to the movement of the MS.

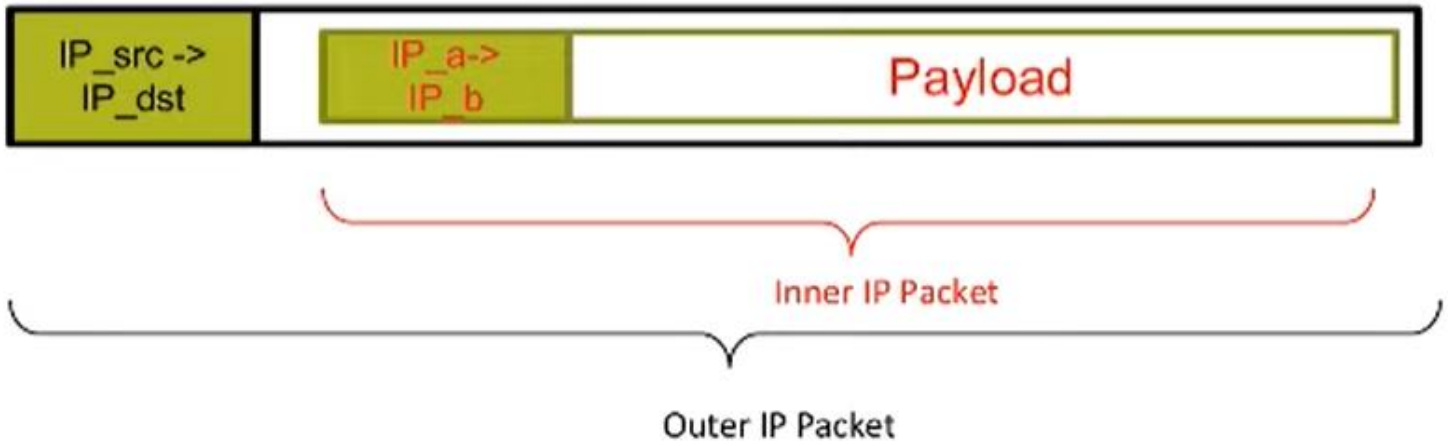


Transition from 2G to 3G (2.5 G)

❑ 2.5G technologies

➢ GPRS: Session management

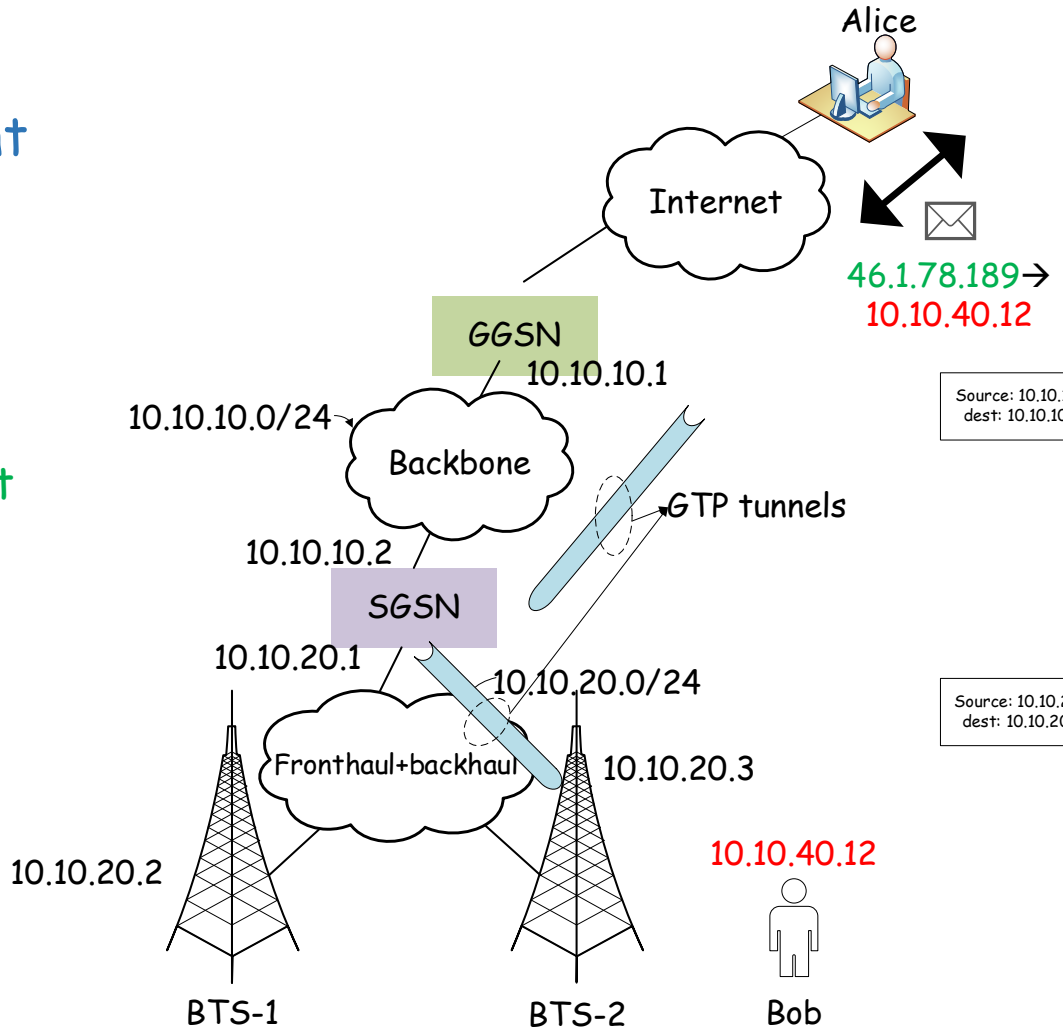
- ✓ GTP=GPRS Tunneling Protocol
- ✓ What is Tunneling in the IP world
  - Tunneling means putting an IP packet inside of another IP packet



Transition from 2G to 3G (2.5 G)

2.5G technologies

- GPRS: Session management
  - ✓ What is the purpose of GTP Tunneling?
    - Routing an IP packet along a path that is topologically incorrect for the packet.



Source: 10.10.10.1 dest: 10.10.10.2	UDP port#: 2152	TEID1	Payload Source: 46.1.78.189 dest:10.10.40.12

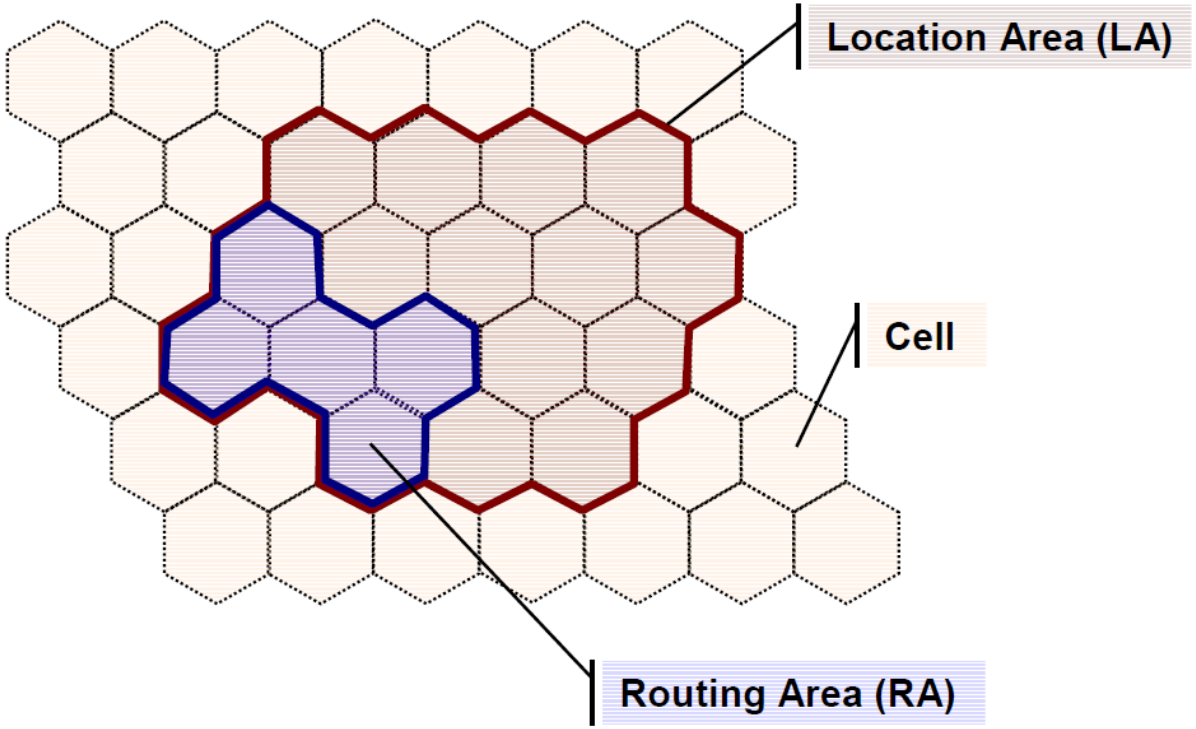
Source: 10.10.20.1 dest: 10.10.20.3	UDP port#: 2152	TEID2	Payload Source: 46.1.78.189 dest:10.10.40.12

Transition from 2G to 3G (2.5 G)

❑ 2.5G technologies

➢ GPRS: Location management

✓ LA > RA > Cell

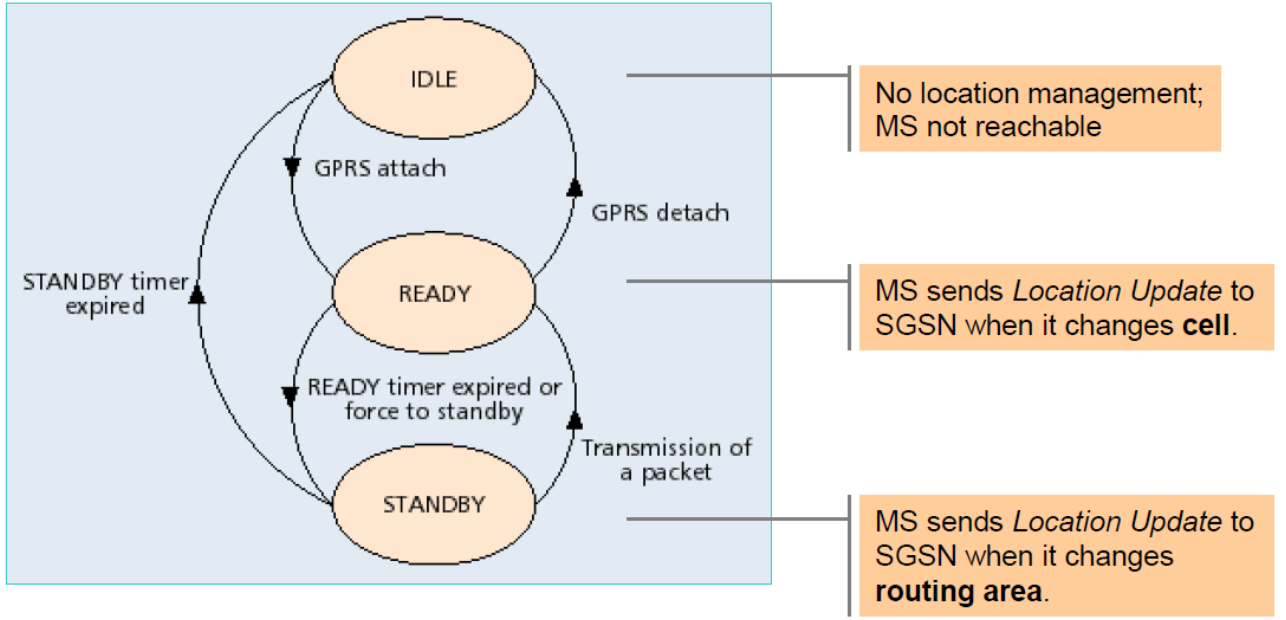


Transition from 2G to 3G (2.5 G)

❑ 2.5G technologies

➢ GPRS: Location management

- ✓ Each MS may update its location based on its status.
  - Idle: An MS behaves like any other GSM phone. It is not attached to GPRS mobility management yet. The SGSN contexts hold no valid location or routing information for the subscriber.
  - Standby: An MS is attached to the GPRS network, but is not ready for sending/receiving data.
  - Ready: An MS is ready for sending/receiving data.



Transition from 2G to 3G (2.5 G)

2.5G technologies

GPRS: Location update

Intra-SGSN routing area update	MS moves to an RA that is administered by the **same** SGSN as the old RA.
	SGSN has stored user profile Assigns new P-TMSI
Inter-SGSN routing area update	MS moves to an RA that is administered by a **different** SGSN as the old RA.
	New SGSN requests profile from old SGSN SGSN informs all GGSNs, HLR, and VLR

Transition from 2G to 3G (2.75 G)

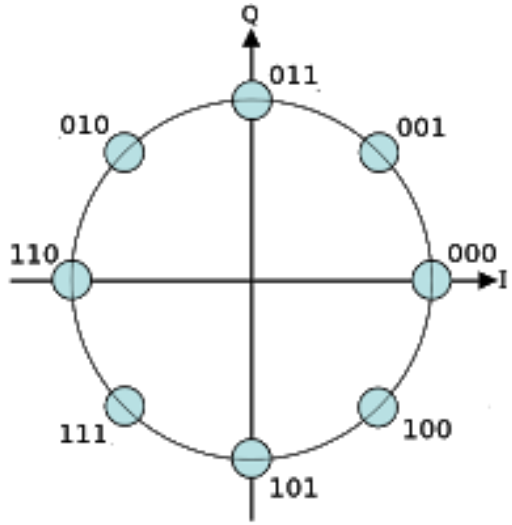
❑ 2.5G technologies

➢ Enhanced Data Rate for GSM Evolution (EDGE)—2.75G

- ✓ Apply the same network architecture
- ✓ Modulation: GMSK→ 8-PSK (Phase-shift keying) in good channel condition
  - Eight different phase angles are used to represent three bits

$$s_i(t) = Acos(2\pi f_o t + \frac{2\pi}{M}) \text{ ,where } i = 1, 2, \ldots, M-1$$

  - One symbol contains 3 bits.
- ✓ Coding Adaption: More user data bits, and less error correction bits in good channel condition.
  - Data rate: up to 473.6 kbps.



Constellation diagram

Transition from 2G to 3G (2.75 G)

❑ 2.5G technologies

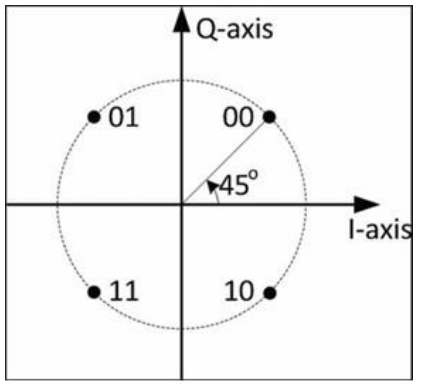
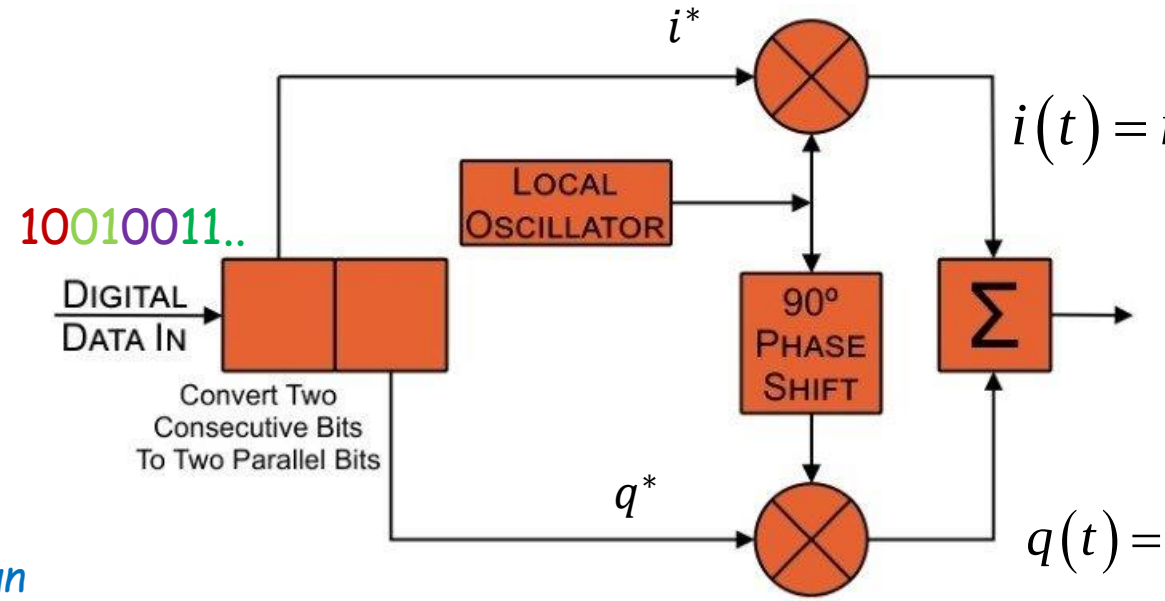


Figure 1. Constellation View of QPSK

➢ More about the modulation scheme (QPSK, 8PSK, 16QAM, 64 QAM,…)

✓ Quadrature Phase Shift Keying (QPSK)

- Digital data stream is processed so that two consecutive bits become two parallel bits.
- Two I/Q signals are generated, i.e., $i(t)$ and $q(t)$. In QPSK, $|i^*| = |q^*| = a$.
- Two I/Q signals are summed up to generate a QPSK symbol $y(t)$, where $\theta = \arctan\left(\frac{q^*}{i^*}\right)$.
- One QPSK symbol can carry 2 bits.



$$i(t) = i^* \cos(2\pi f_0 t)$$

$$y(t) = \sqrt{(i^*)^2 + (q^*)^2}\cos(2\pi f_0 t + \theta)$$

$$q(t) = q^* \sin(2\pi f_0 t)$$

Transition from 2G to 3G (2.75 G)

❑ 2.5G technologies

- ➢ More about the modulation scheme (QPSK, 8PSK, 16QAM, 64 QAM,…)
  - ✓ 8 Phase-shift keying (8PSK)
    - Three consecutive bits are group together to modulate an 8PSK symbol.
    - Each type of 8PSK symbol has the same amplitude but different phases.
  - ✓ 16 Quadrature Amplitude Modulation (16QAM)
    - Four consecutive bits are group together to modulate an 16QAM symbol.
    - Each type of 16QAM symbol has different amplitudes and phases.